# Lessons Learned from Interim Volunteer-Plant (VP) ECCS Vulnerability Assessment


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**NEI PWR Sump Performance Workshop**

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# Overview

- Objectives of Volunteer-Plant Analysis
- Plant Description
- Sump-Screen Head Loss
- Pool Transport
- Blow Down/Wash Down Debris Transport
- Debris Generation
- Break Location
- Current Insights

# Objectives of Study

- Volunteer Plant study integrates all phenomenology info and analysis methods using best available plant specific data
- Illustrates one possible implementation of the Reg Guide
- Provides NRC a detailed standard of comparison for reviewing future submittals and NEI ground rules
- May provide a template for content of plant assessments but with exaggerated detail needed for methodology insight
- Sets expectations for conservatism and application of data
- Will address all major accident scenario components BUT… will not analyze all industry conditions/configs
- 'Best Available' info will still require approximation and engineering judgment. Will improve as condition assessment and further head-loss analyses are completed

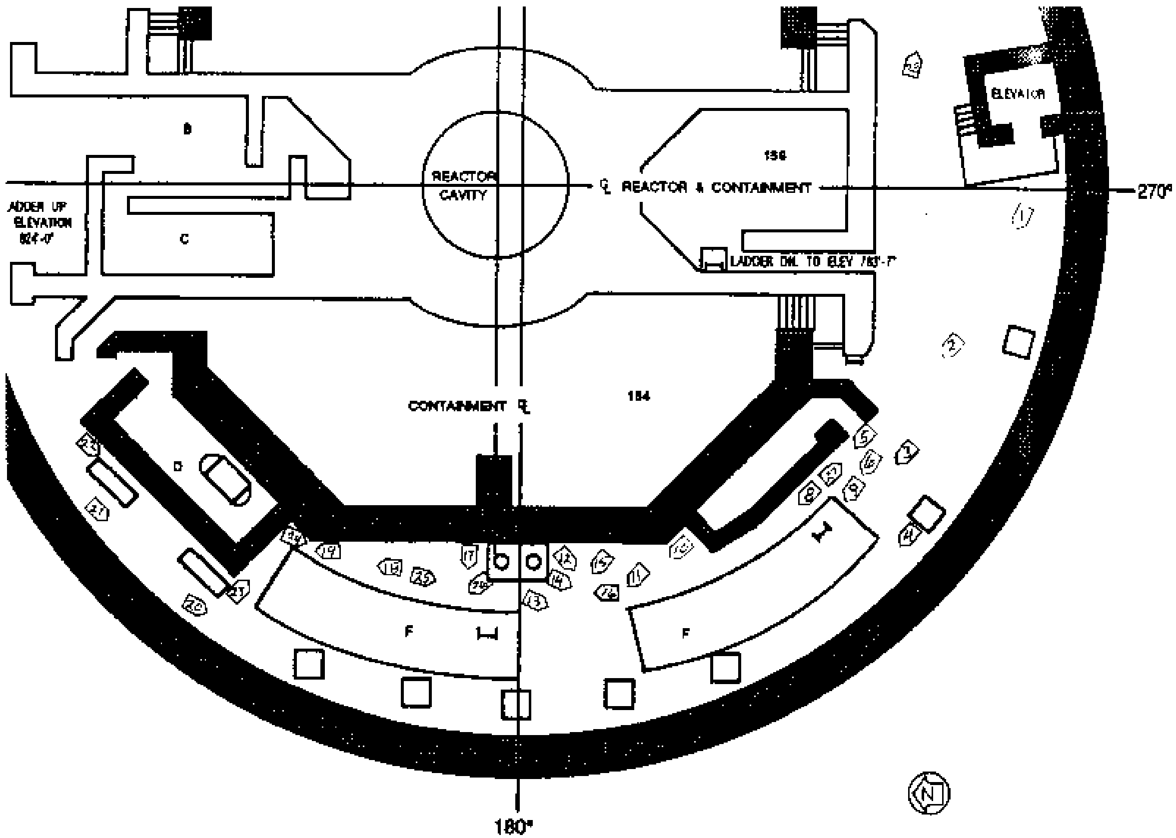
# Required Plant Information

- **Water balance calculations**
  - Return flow locations and rates
  - Minimum pool depths for various break scenarios
  - ECCS flow rates for various break scenarios
- **ECCS pool geometry**
  - Flow velocity calculations
  - Identify dead sumps that can trap debris during fill up
  - Scope pool dynamics (regimes of fill up, spray return, steady-state)
- **Piping layout and insulation applications by type**
- **Sump-screen geometry**
- **Plant cleanliness characterization (Latent Debris)**

# VP Geometry Features

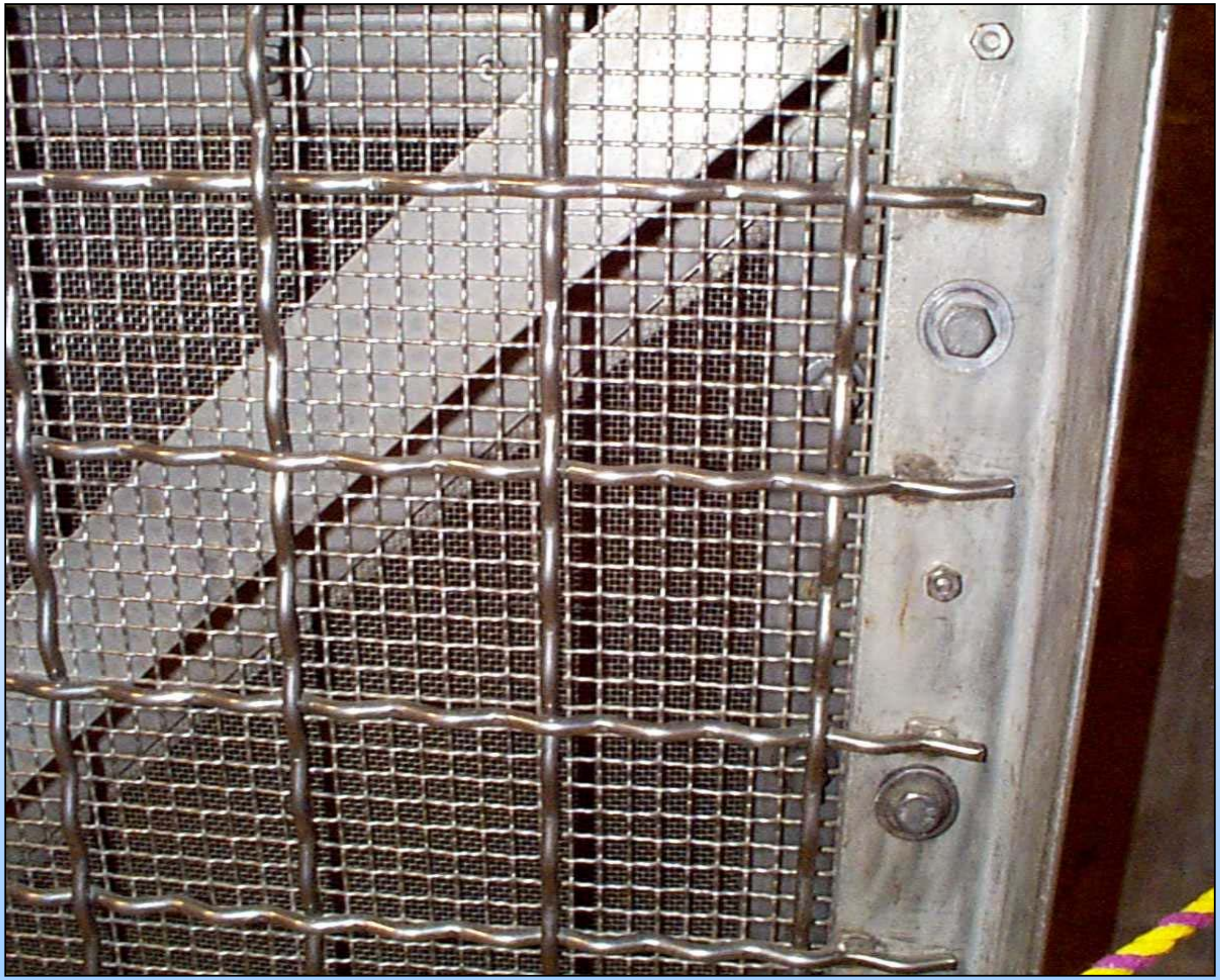
- **Large dry containment (133 ft diam), four loop, ‘remote’ sumps**
- **Raised steam generator compartments**
  - Continual falling water sweeps compartment floor
  - Compartment opposite break cannot accept debris during fill phase
  - No damping of falling water.  Momentum directed to annulus
- **Two adjacent roughly equivalent sump cages (260 $ft^2$ total)**
  - Very close to one steam generator compartment outlet
- **Sump-screen curb (4 in)**
  - Effective at stopping RMI debris unless severe piling occurs
  - Reduces effective pool depth
- **Nonsubmerged vertical sump screens 4.75 ft above curb**
  - Failure criteria ~1/2 pool depth above curb (ft $H_2O$)
- **Fall height from upper level drains ~10 ft**
- **Spray return drains adjacent to vertical sump screens**
- **Reactor cavity access has curb and partial steel-plate cover**

# Sump Pool Plan View



# Sump Cages

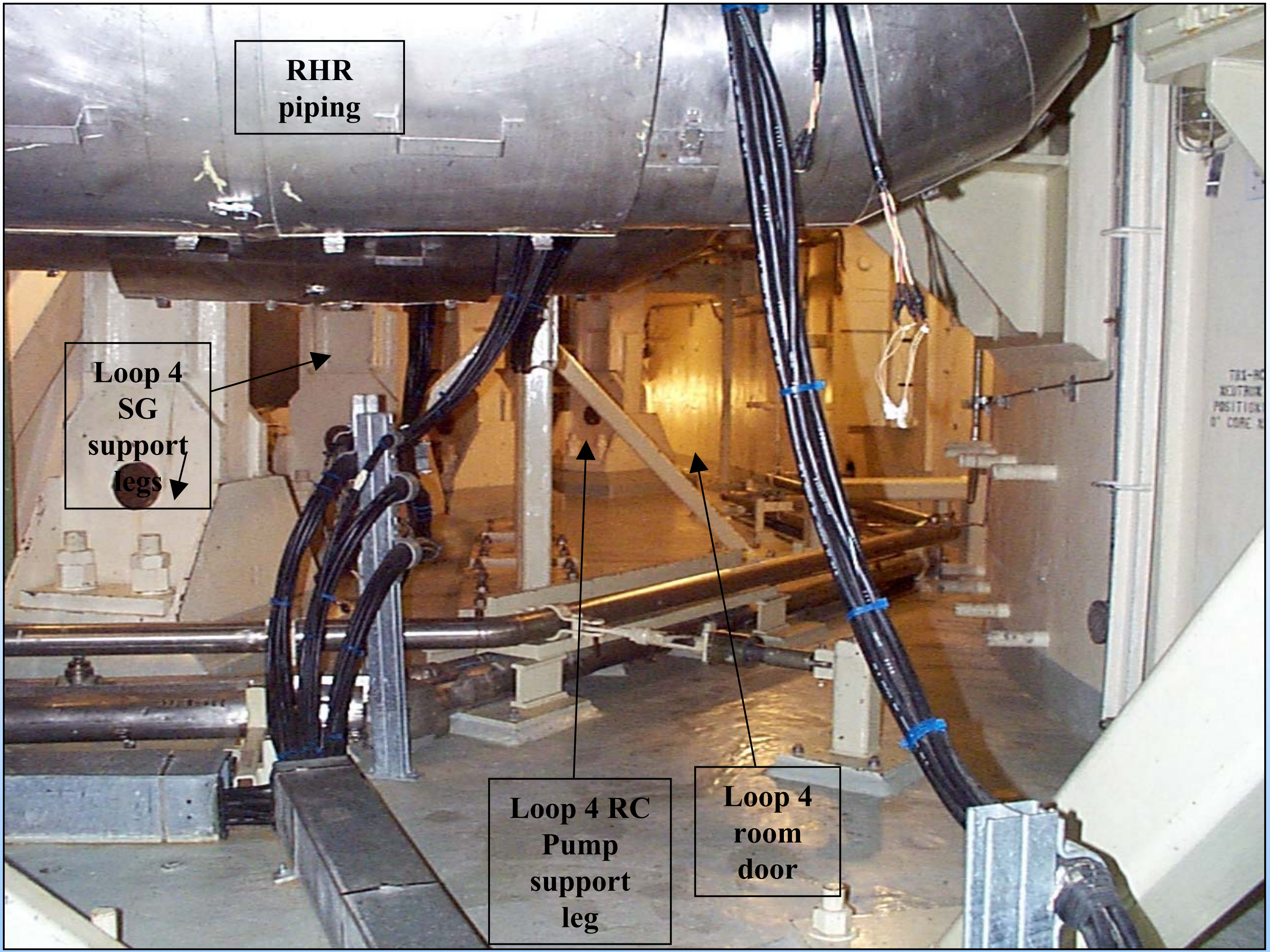
# Sump-Screen Construction



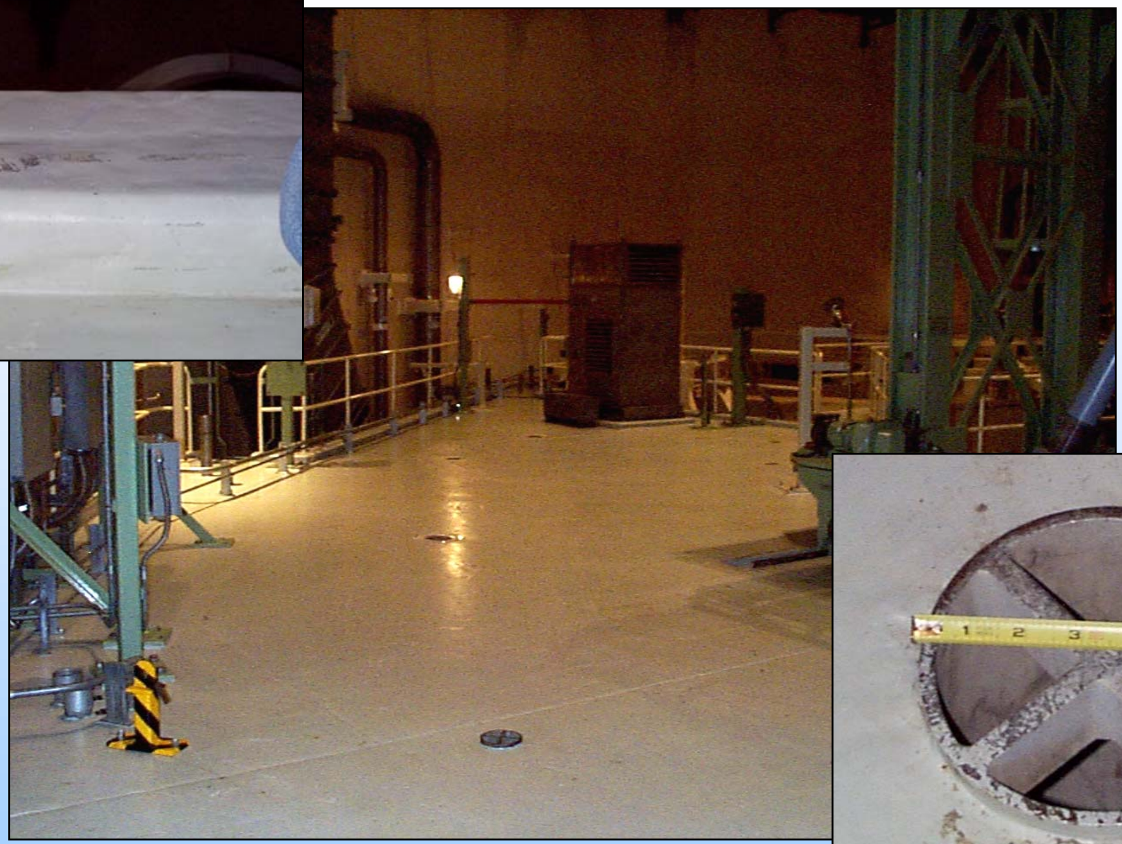
# SG Compartment Entry


- Door closed during operation by radiation safety procedure
  - Intermediate debris trap or water flow blockage?
    - Both compartment doors must block to prevent flow yet large fraction of total debris may pass through these doors
    - Comparison of compartment fill up rate may show that structural failure loads are reached before switch over

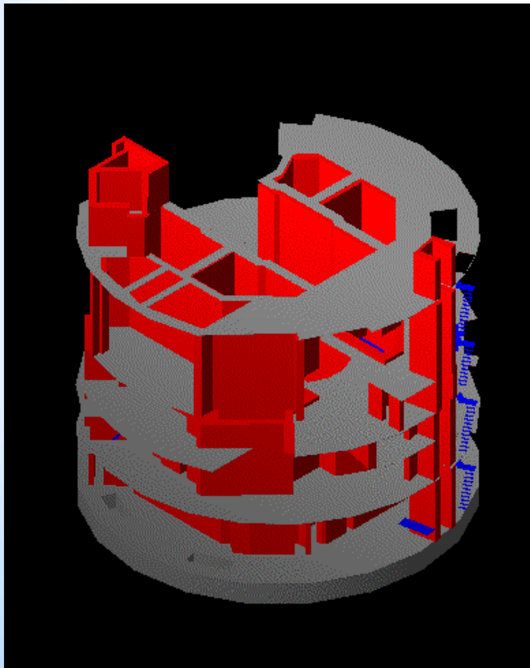
# Steam Generator Compartment



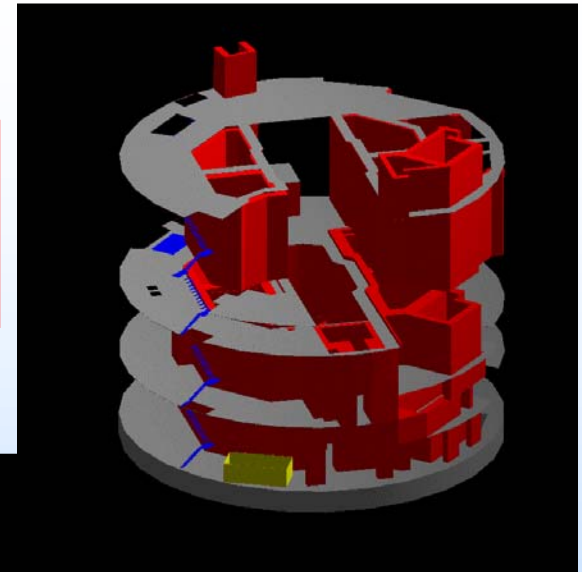
# Floor Drains and Curbing

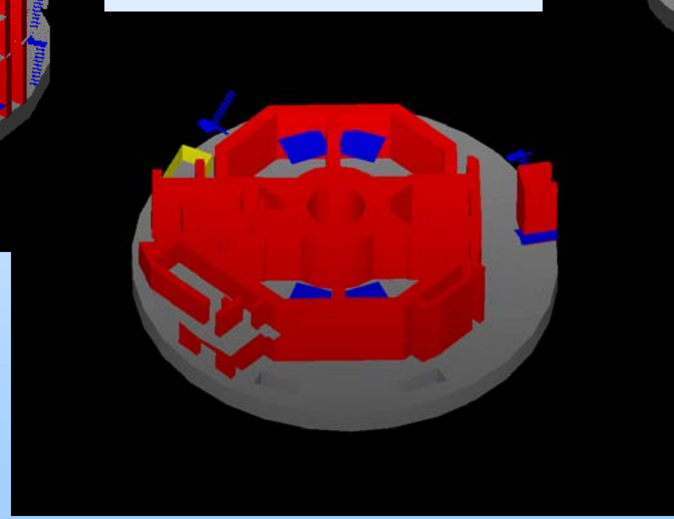


# Concrete Structures

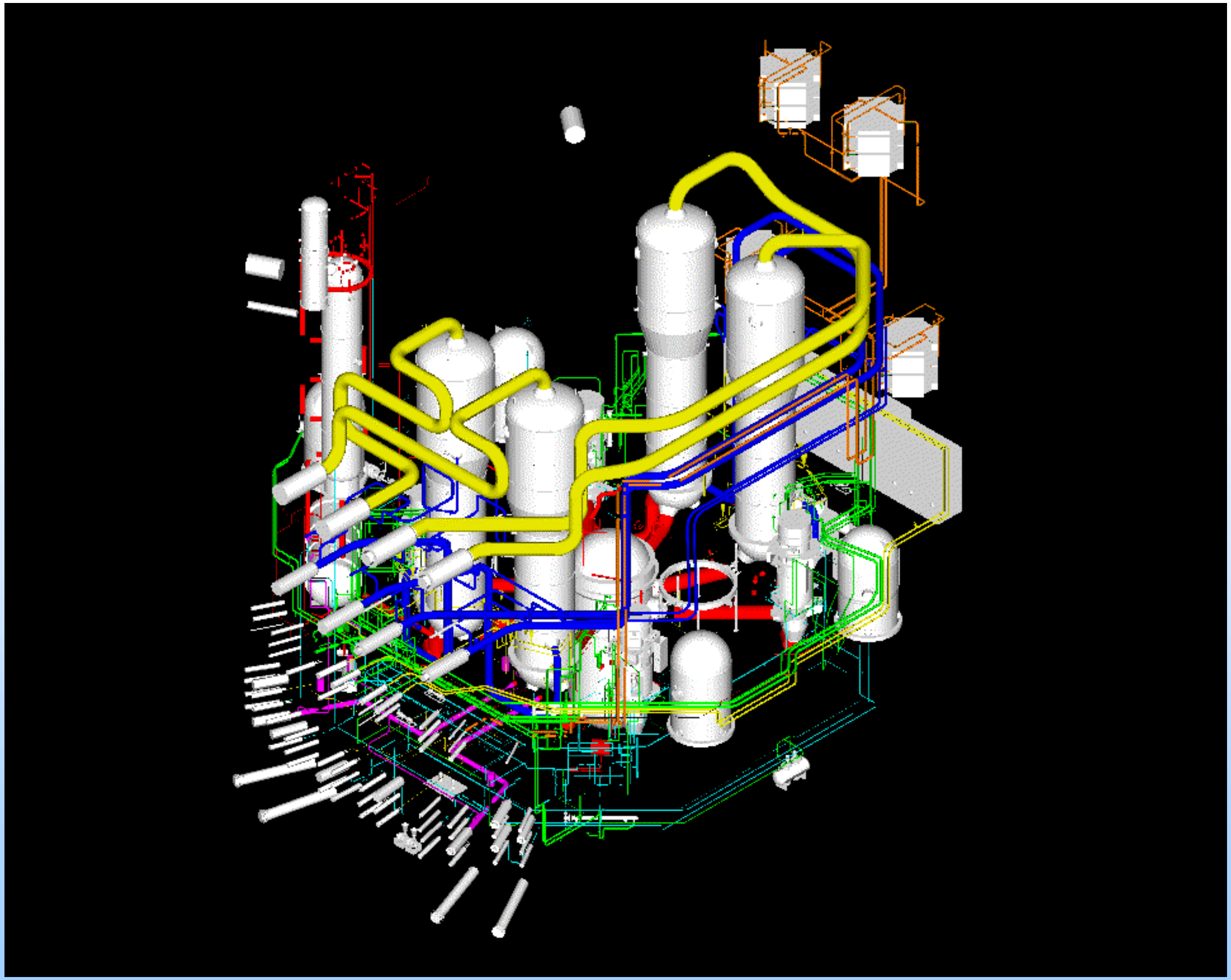


CAD model constructed by tracing plan view of each level

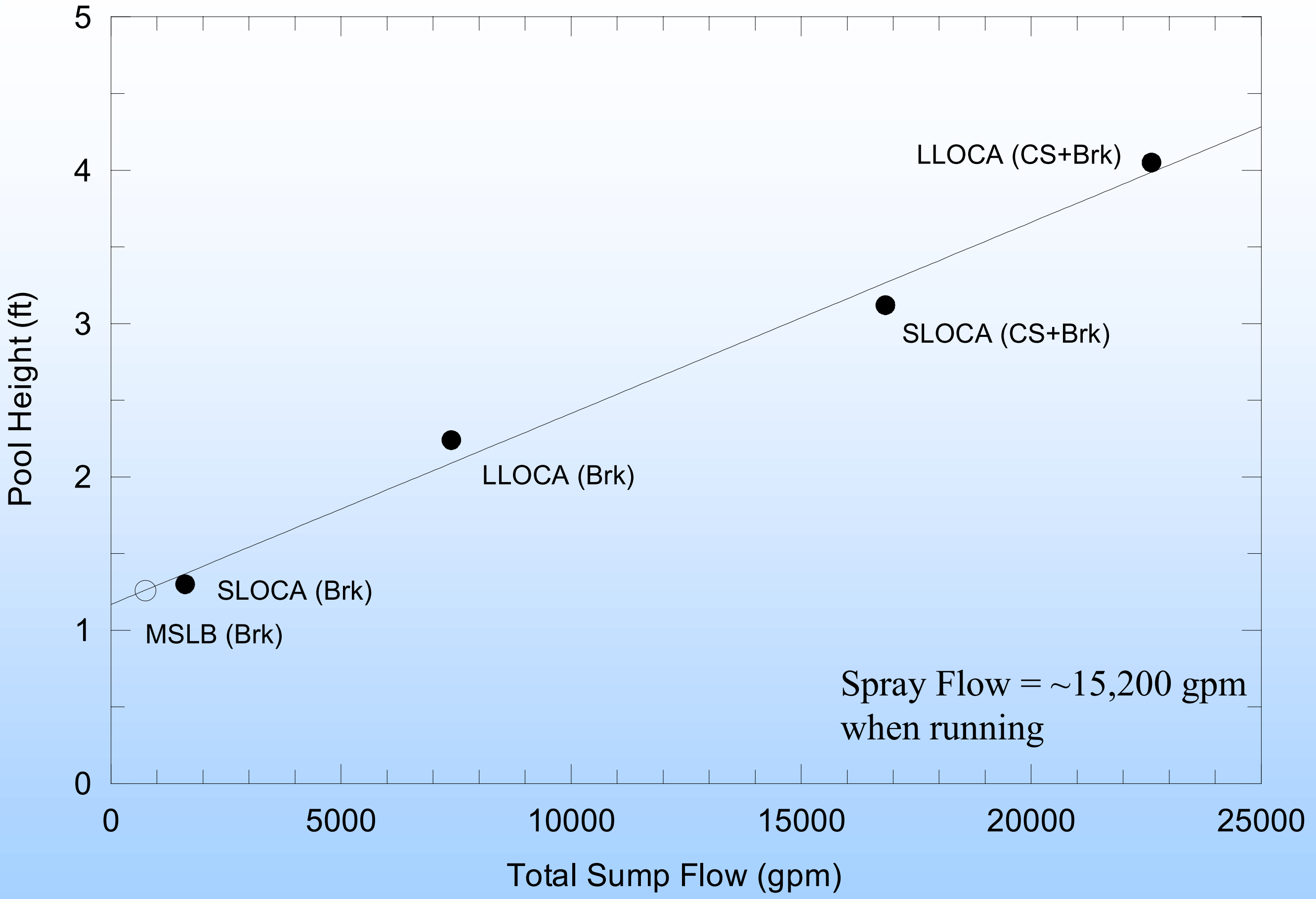




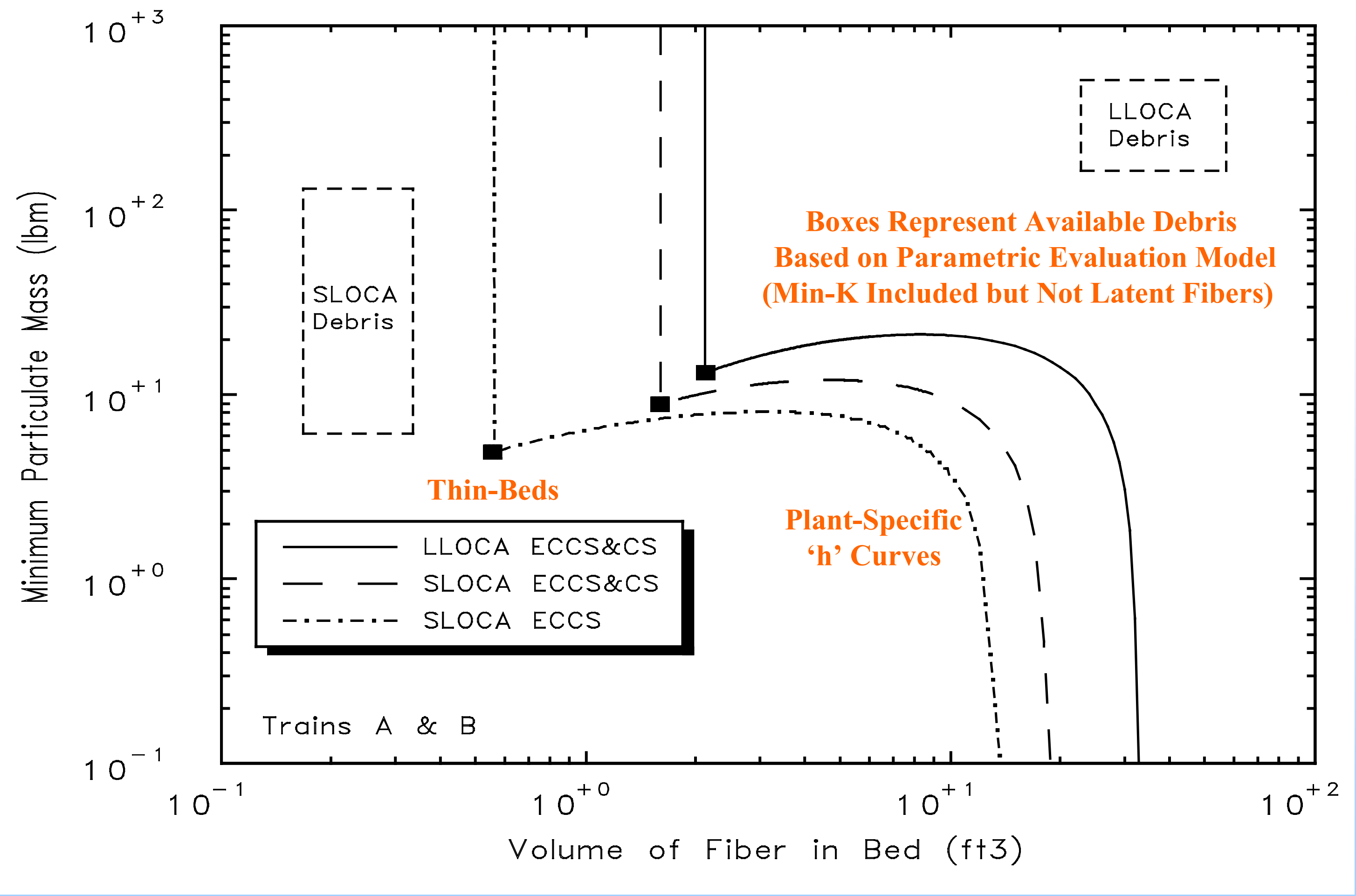
# Piping and Equipment Model



# Ranges of Sump Flow

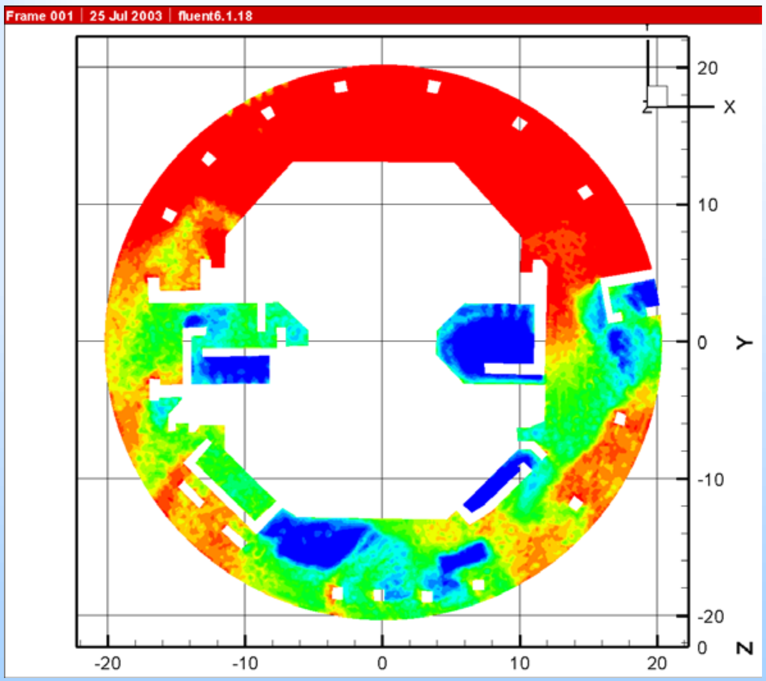


# Head-Loss Vulnerability Assessment

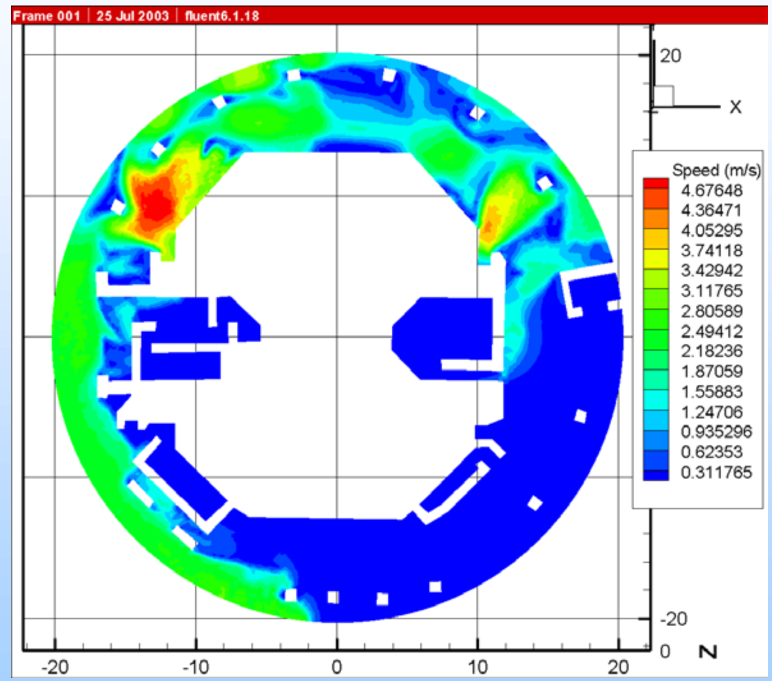


# Containment Pool Flow Analysis

- Fluent fill up calculation with 7400 gpm break in upper left quadrant
- CS return cascades begin to hit pool at about 90s.  Difficult to compute

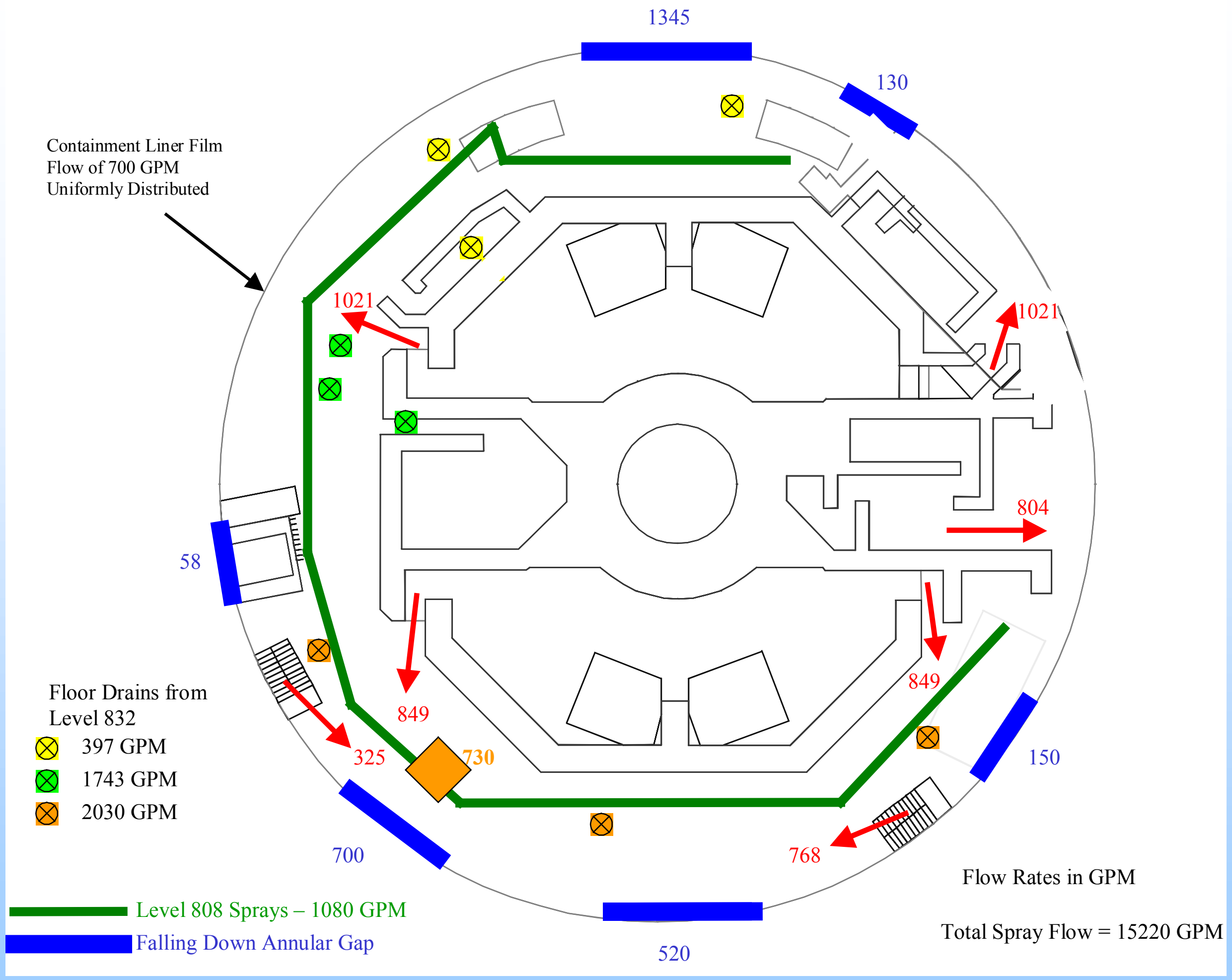



Volume fraction at 90 s and 0.1 m height




Velocities typical during fill up

# Estimated Spray Return Cascades



# Observations Regarding CFD

- **Good qualitative agreement between CFD models of fill/steady-state velocities and Tank Experiments**
- **Ancillary sources representing containment spray return paths can dominate pool activity**
- **Quantitative flow maps provide access to an approximate, yet tractable estimate of transport fraction**
  - Logic maps and engineering judgment will be needed to consider fractions and characteristics of debris returned to the pool via various paths
- **Uncertainties in location and timing of debris entering pool limit the need for a high fidelity model of debris transport**

Area > threshold velocity proportional to degradation and transport for initial uniform distribution of fill-up phase debris

# Transitional Pool Flow Sequence

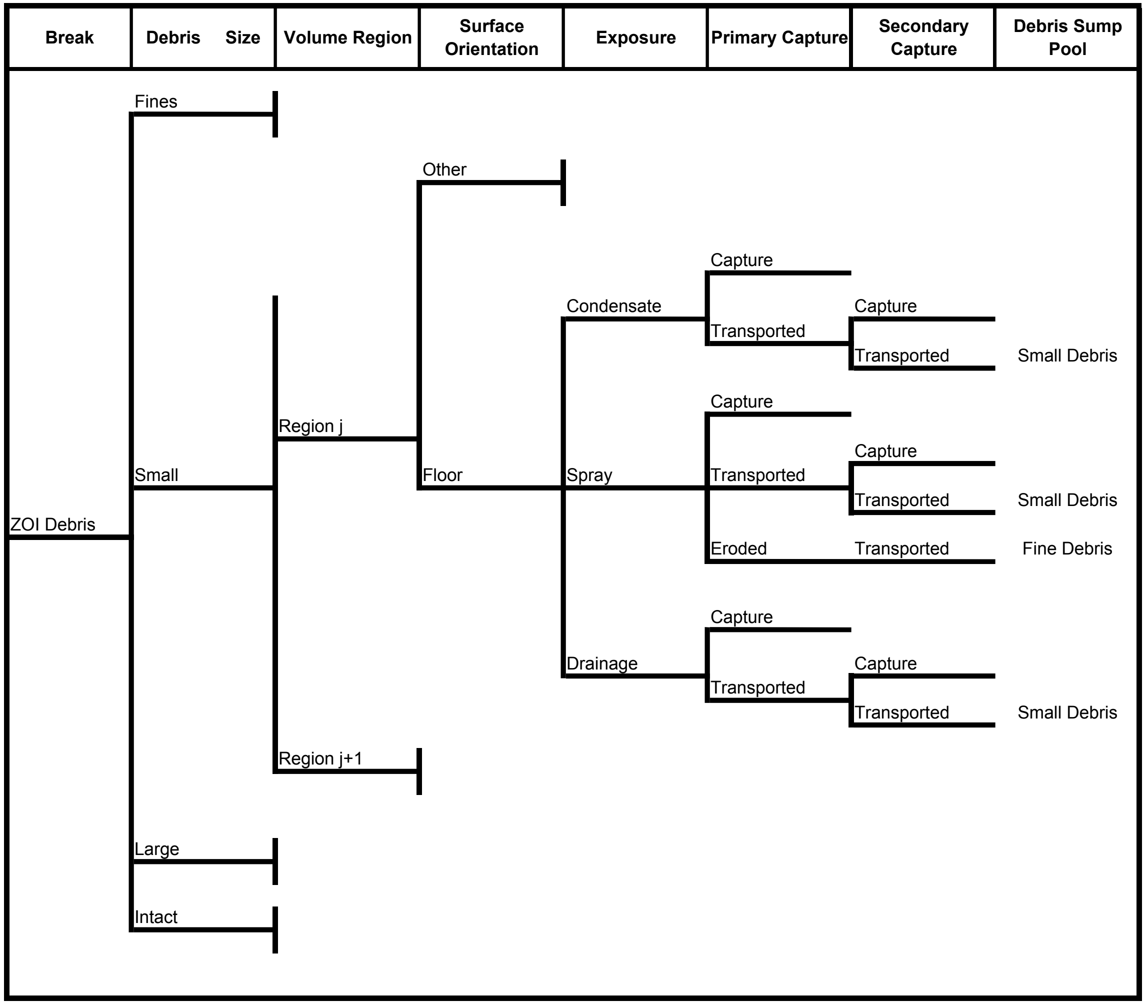
| Event | Characteristics |
|---|---|
| Break Occurs | Jet impingement, steam expansion, water to bare floor with sheet flow directed away from break. Highest transport velocities. Initial deposition pattern in dead areas and sumps. |
| Sprays Trip | Spray runoff accumulates and washdown begins, Sheet cover complete. Sumps fill via directed flow. Deposition pattern modified by splash zones |
| Max Spray Return | Maximum energy in minimum pool depth (~inches). No directed flow. Pool begins to fill. Max degradation. Pseudostable deposition pattern develops. |
| Lower Sumps Full | Directed flow begins to develop. Deposition pattern modified in vicinity of sump. Suspended debris collected very quickly. Steady-state flow pattern established. |

**Dead sump sheltering is only significant sequester**

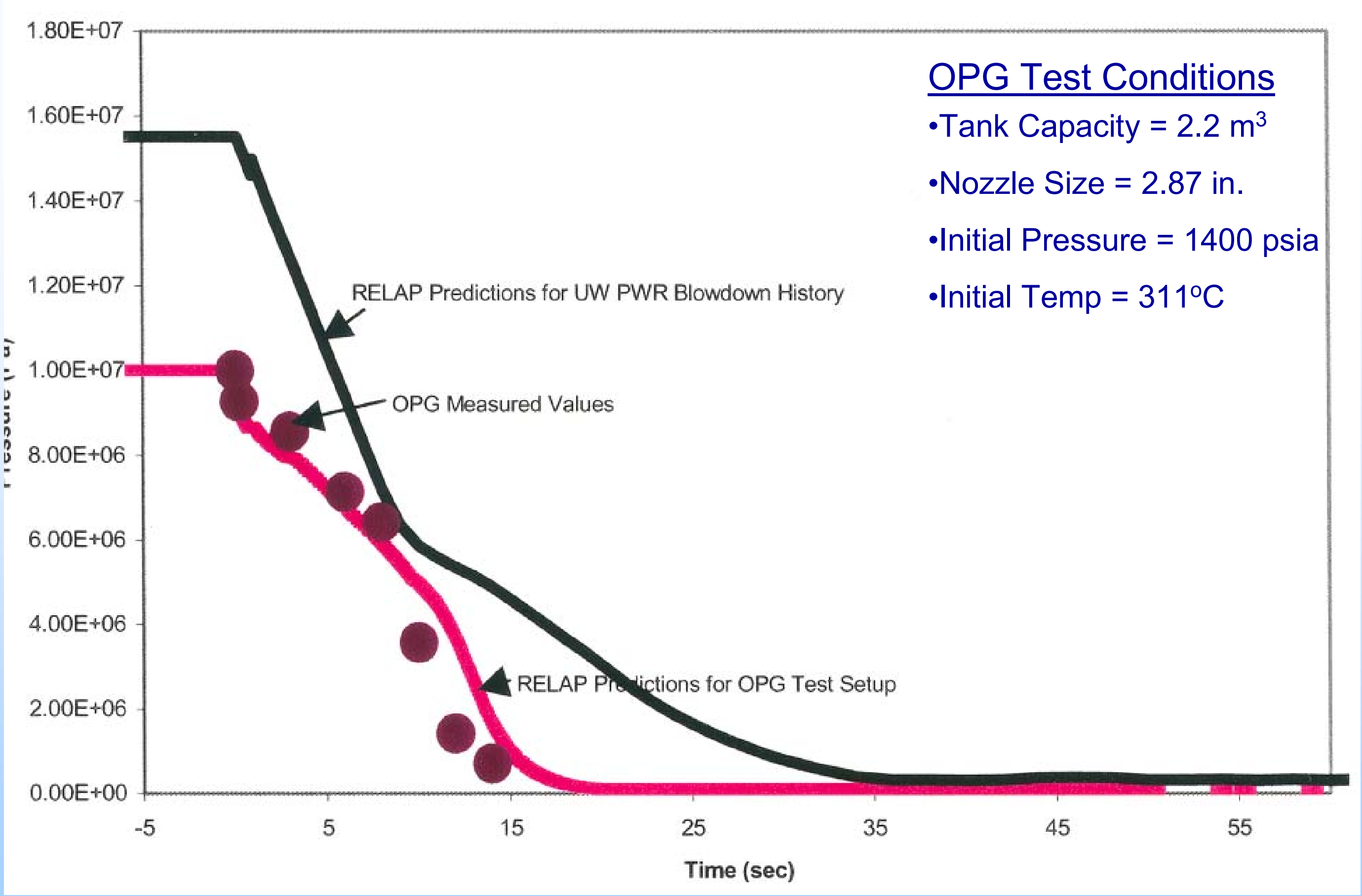
# Key Transport Test Observations

- Cal-Sil and fiber were able to form a thin bed on a ¼-in mesh vertical screen at nominal approach velocity
- Fiber flocks that enter turbulent splash zones are effectively shredded to transportable sizes
- Individual fibers are suspended and continue to collect for many hours
- Shear forces between higher and lower pool velocity zones may be capable of slowly degrading piles of fiber flocks

# Containment Airborne/Washdown Debris Transport Logic Chart



# Two-Phase Debris Generation



# Survey of Break Locations

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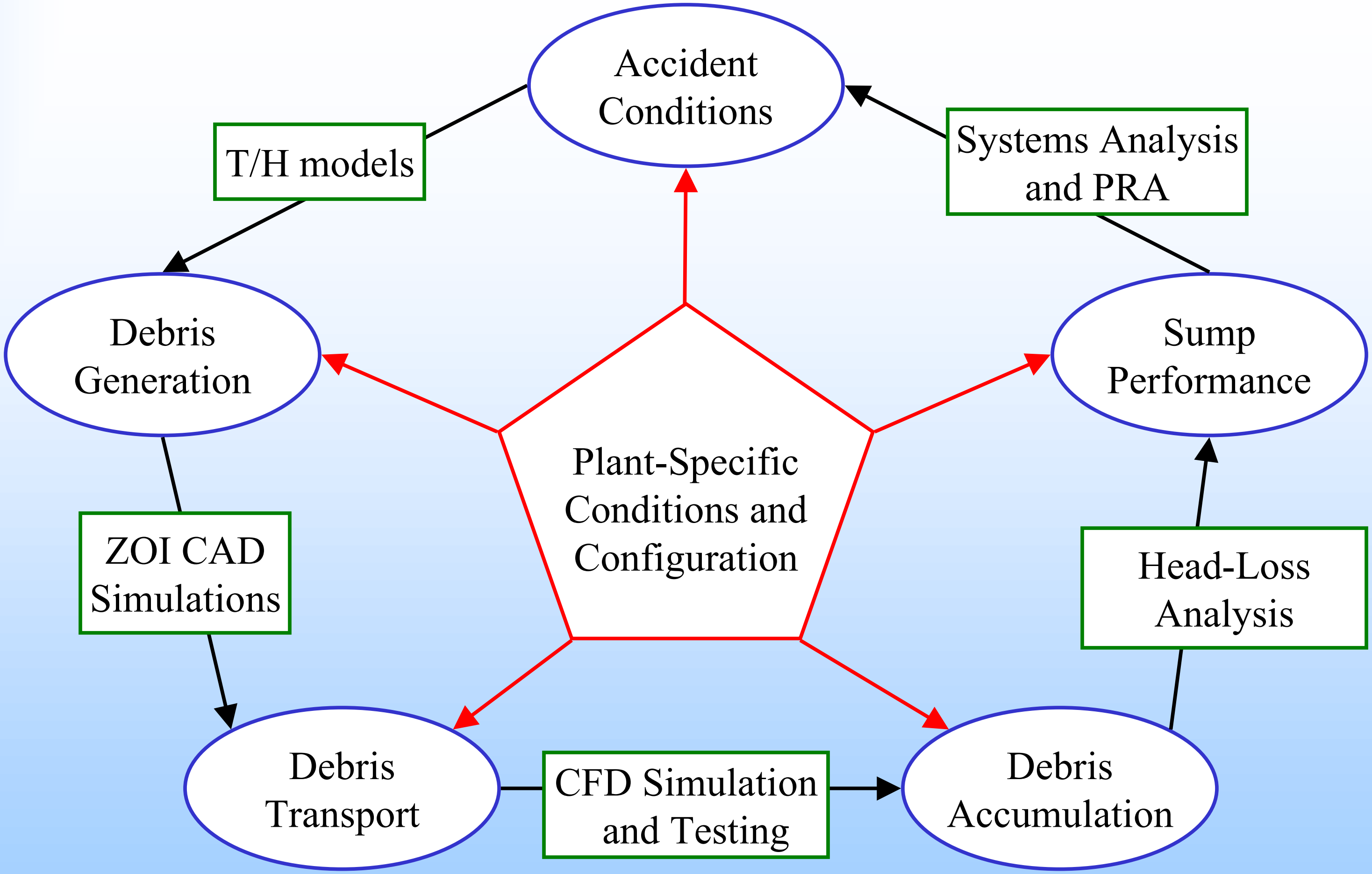
# Integrated Vulnerability Assessment



# Required Skill Set

- **Familiarity with containment**
  - Visual understanding of spray and floor water flow paths
- **Understanding of water levels and pump-flow rates as related to EOPs**
- **Competent application of BLOCKAGE or other implementation of NUREG/CR-6224 head-loss correlation**
  - All plants should start by understanding current sump vulnerability
- **Understanding of ZOD correlations to scope break locations**
- **Knowledge of applied insulation types and ability to query/manipulate electronic spatial information**
  - CAD models desirable, but not critical
- **Awareness of debris generation and head-loss data**
  - Identify unique materials and plan for characterization

# Methodology Insights

- **Design/adapt screens to defeat thin-bed formation**
  - Transverse bulk and inlet flows to sweep or 'self-clean' surface
    - Stacked disks, crenulated plates, etc.
  - Complex filter surface to fragment fiber layer
- **Can mitigate to protect against large debris volumes**
  - Reducing insulation volume
  - Increase screen area with compact high surface modifications
  - Intermediate gates at pool level
  - Divert fill-up flow towards dead sumps/cavities
- **Always maximize pool depth**
  - Especially important for nonsubmerged screens
  - Run sprays for breaks of all sizes?
- **Special attention to cleanliness at pool level for small break/no spray**
- **Fill-up retention in dead sumps is perhaps the only important pool-transport reduction factor**

# Mitigation Strategies

## Preserve Integrated Safety Plan!

- **Submerge screens without compromising area**
  - Utilizes full NPSH margin of mechanical pumps
- **Avoid horizontal screens below grade**
- **Test and approve back-flush/throttle cycles to dislodge compacted debris**
- **Midstream debris screens to intercept steady-state flow channels**
- **Plant cleanliness programs**
- **Modification of insulation types**
  - With due care not to increase resident loading
- **Active mechanical sweep and collect concepts**
- **Innovative porous media designs on top of existing screens**
- **Multiple inclined screen surfaces that fall away to expose new area**